

PRELIMINARY RESULTS FROM AN IN-SITU COAL GASIFICATION  
EXPERIMENT USING EXPLOSIVE FRACTURING\*

Charles B. Thorsness, Richard W. Hill, and Douglas R. Stephens

Lawrence Livermore Laboratory, University of California  
Livermore, California 94550

INTRODUCTION

After almost two decades of inactivity the field of in-situ coal gasification has experienced a recent renaissance. There is at least one current industrial project, that of Texas Utilities Generating Co. in Texas lignite. They are using the very extensive Soviet technology to develop in-situ coal gasification to produce low Btu gas for electrical power generation. Three ERDA-sponsored projects are in the field, testing different modes of developing permeable paths in coal beds. The Laramie Energy Research Center is developing reverse combustion techniques to link vertical wellbores; the Lawrence Livermore Laboratory is developing explosive fracturing to create an underground packed bed; and the Morgantown Energy Research Center is developing directional drilling techniques to establish linking.

Sandia Laboratories are developing advanced instrumentation techniques for monitoring in-situ coal gasification and are cooperating with the Laramie Energy Research Center in their underground coal gasification experiments near Hanna, Wyoming. The Alberta Research Council is fielding a project near Edmonton, Alberta. Texas A & M University is fielding an experiment near College Station. The University of Texas is performing extensive systems studies on coal gasification in Texas lignite, while other in-situ coal projects are underway at the Universities of Wyoming, New Mexico, Alabama, Kentucky, West Virginia and the Pennsylvania State University. In addition, coal pyrolysis and kinetics studies are being conducted at the ERDA National Laboratories at Oak Ridge and Argonne.

The reasons for the extensive in-situ coal gasification programs are many-fold. Among them are: (1) the promise of relatively low-cost energy from in-situ coal gasification, at least as compared to other alternate fuels. (2) The promise of relatively low environmental impact from these in-situ processes. (3) The opening up of new coal reserves for development which may be uneconomic by other techniques. (4) The rather recent discovery that the Russians developed very successfully in-situ coal gasification techniques in the late 1950's, and applied them at the demonstration or pilot plant level (up to 500 tons of coal consumed per day) for up to 20 years.

In this report we summarize a recent field experiment in the ERDA-sponsored underground coal gasification program at the Lawrence Livermore Laboratory. Our project objective is to develop a commercial underground coal gasification process by using explosives to fracture the coal in place to create selectively enhanced permeability. (1) The resultant permeable coal would be gasified with steam and oxygen and the gases would be upgraded to pipeline quality in surface facilities.

Our first field gasification experiment, called Hoe Creek #1, was conducted in two phases: phase #1 included site characterization, fracturing and preliminary permeability measurements and has been reported. (1a) It is briefly described in this report, but the primary purpose of this paper is to describe phase #2 of the experiment, which included detailed fracturing and permeability measurements followed by in-situ gasification.

---

\* This work was performed under the auspices of the U.S. Energy Research and Development Agency.

### Phase #1: Site Characterization and Fracturing

One and two-dimensional computer codes, using compressive shear failure as a criterion, were used to design a multiple explosive field fracturing test, Hoe Creek #1. Extensive coal mechanical properties were input to the codes, which were normalized with laboratory fracture experiments and an earlier field test at a coal outcrop using 130# of explosives. (2)

The experimental Hoe Creek site is in the Powder River Basin, 25 miles SW of Gillette, Wyoming, in the 25' thick subbituminous Felix #2 coal at a depth of 125'. The stratigraphy of the site was derived from cores, drill-cutting samples, and downhole geophysical logs and is shown in Fig. 1. Table 1 gives the chemical analysis of the Felix #2 coal. (3) Experiment #1 was a simple two-spot fracturing experiment which was carried out at Hoe Creek on November 5, 1975.

Table 1. Analysis of coal from the Felix No. 2 seam.

<u>Proximate analysis (%)</u>			<u>Ultimate analysis (%)</u>		
	<u>As received</u>	<u>Dry basis</u>		<u>As received</u>	<u>Dry basis</u>
Moisture	29.2	—	Moisture	29.2	—
Ash	6.37	9.00	Carbon	47.41	66.96
Volatile	31.90	45.06	Hydrogen	3.53	4.99
Fixed carbon	32.53	45.94	Nitrogen	0.91	1.28
	100.00	100.00	Chlorine	0.01	0.02
			Sulfur	0.62	0.88
Btu	8156	11522	Ash	6.37	9.00
Sulfur	0.62	0.88	Oxygen (diff)	11.95	16.87
				100.00	100.00

The purpose of the experiment was to do a small scale study of explosive fracture and gasification. It was designed to provide information on well survival, drilling techniques in fractured coal, the permeability enhancement created by two HE shots, gas flow rates, liquid plugging, burn over-ride, etc. It consisted of two 750# explosive charges fired simultaneously at the bottom of the coal seam at a depth of 150'. The explosives were placed at the bottom of the seam to enhance the permeability there for better liquid drainage and gas flow. Prior to fracturing, the site geology, hydrology and permeability were carefully characterized. (4) Post fracture characterization of the site, in late 1975, using hydrology showed that the coal permeability was stimulated from .3 darcy preshot to about 2-4 darcies postshot. (5)

During 1976 we returned to the experiment to redetermine the fracturing, take cores, remeasure the permeability distributions, dewater the coal, measure air flows, and, finally, gasify the coal.

### Phase #2: Site Plan and Instrumentation

The final, as-built, well pattern for phase #2 is shown in Fig. 2. Well I-0 was steel cased to the top of the Felix No. 2 seam and communicates directly with

the rubble-filled HE cavity below it. Well P-1 was steel cased and cemented within the bottom 5' of the coal bed. The HE well was cemented to the surface after the shot. All of the wells I-1 through I-8 were uncased instrument wells. They contained thermocouples and tubes for water level measurements and gas sampling.

The dewatering wells DW-1 thru DW-6 were steel cased to the top of the coal, screened thru the coal and had a steel pump section below the coal. These wells each contained a 25 gpm capacity water pump in the sump section. The preliminary hydrology tests indicated that calculating the well distribution required to dewater this very non-homogeneous zone would be very difficult. Therefore, we decided to surround the anticipated burn zone with dewatering pumps. The positions of DW-1 and DW-6 were chosen to give two different radial distances from a shot center for permeability measurements.

Installing the instrument packages in uncased holes close to the shot points was accomplished successfully but not without some difficulty. Once the drill reached the bottom third of the Felix No. 2 seam, wall collapse became a serious problem. All drilling was done with air and foam to prevent clogging of the fractured coal but this provided no stabilization for the hole walls in the highly fractured coal. Most of the instrument emplacements were done by flowing water into the hole as the instrument package was being lowered.

No unusual problems were encountered during the construction of the dewatering wells, although the driller did notice that the major zone of water production within the Felix No. 2 seam was in the top few feet for all the wells drilled.

This program is described in more detail in reference 6.

In the design of the instrumentation for this experiment, we decided to concentrate on three major measurement requirements. They were; air and gas flow rates, product gas composition and gasification zone temperature distribution.

The air and gas flow rates were measured with standard orifice plates using remote readout pressure transducers and thermocouples for the P,  $\Delta P$ , and T measurements. These data, as were all others, were recorded on strip charts in parallel with a data logger that recorded digitally on magnetic tape.

The orifice flow meters were rugged and survived flooding with water, tars, and coal fines. Maintenance was inconvenient and messy but it was possible.

The product gas composition was measured with two on-line gas chromatographs that sampled automatically at hourly or shorter intervals throughout the experiment. The operation was quite successful with no major problems.

Two of the instrumentation wells, I-1 and I-2 were constructed during the first phase of the experiment. These wells contained three thermocouples each with one at the top, center and bottom of the coal seam. The other instrument wells, I-3 through I-8, each contained seven thermocouples distributed as shown in Fig. 3.

Each instrument well also contained a stainless steel tube used for water level measurement. This was accomplished by bubbling air through and measuring the hydrostatic pressure. Several of these plugged with coal fines but enough were available to satisfactorily complete the hydrology measurement program. During the gasification period the bubbler tubes were used as gas pressure indicators and to extract gas samples from the burn zone.

Three wells, CB-1, CB-2, and CB-3, had a stainless steel tube sealed in place for use with a movable thermocouple. Only well CB-2 ever showed a substantial temperature rise and that only near the end of the gasification period.

The fixed thermocouples were 1/8" diameter stainless steel sheathed chromel-alumel. They were enclosed in a stainless steel housing to provide mechanical protection. The thermocouples all operated satisfactorily until the burn front actually reached the well. Most of the thermocouples that were exposed to high temperatures (approximately 1000°C) eventually burned out. The failure indication was a change in resistance as they shorted out and formed new junction points. The time of failure was determined by inspection of the temperature records for erratic behavior or, in most cases, when all thermocouples in a well indicate the same temperature.

#### Coring and Hydrologic Testing

Examination of cores taken after the blast showed moderate to heavy fracturing in the upper few feet of the coal bed, then a lesser fractured zone in the middle, and a highly pulverized zone at the bottom 5-10' of the coal bed. Core from the holes between the two explosive charges showed the most fracturing while core from the holes farthest out the least. Correspondence of the degree of fracturing with one and two dimensional explosive code calculations is building confidence in our ability to calculate the extent of fracturing. However, a review of flow behavior pre and post explosion led to the conclusion that permeability is not a simple function of the degree of fracturing.

We found, in general, that postshot wells completed in the lower part of the coal bed showed that the coal in these regions was of lower permeability than preshot. Well P-1, when initially completed, produced an order of magnitude less water than a preshot well, until extensive cleaning operations finally opened up a connection from it to well I-5. (6,8)

Analysis of the drawdown measurements (9) shows three major regions of permeability; a native region of 0.3 darcy permeability at radial distances greater than 50 feet, a high (10-20 darcy) inner core region within 10 feet of the HE wells and an intermediate enhanced region (1/2 to 3 darcy). These values of permeability represents averages over the coal thickness.

Slug and pulse test showed similar patterns but also indicated a considerable degree of heterogeneity in these three regions.

Our interpretation of the hydrology and coring data is the following. The fracturing resulting from the explosive charges enhanced the average permeability in the vicinity of the charges, when the seamed is viewed in a two dimensional areal perspective. However, when viewed in cross section it appears that at certain vertical locations near the explosive charges, the permeability is below preshot levels. This is believed to be a result of plugging by coal fines produced by the intense close-in fracturing. Consequently although the explosives were emplaced at the bottom of the coal bed, much of the permeability enhancement apparently tended to be near the top of the seam.

## Dewatering

Dewatering rates were in good agreement with estimates. (10) After a few hours of higher flow rates a relatively constant rate of water withdrawal of approximately 10 gpm was observed. This withdrawal rate was maintained until pressurization during air flow tests cut the rate to near zero.

Figure 4 shows the actual water levels observed at various observation points in the fractured coal. Water levels indicated at the right-hand side of the figure were measured 3-5 days after start of dewatering. Wells DW-1 through 6 and P-1 were pumped below the coal seam bottom. Wells EM-4 and EM-5 were approximately 50 feet east of the HE wells and EM-1, 2, and 3 were 100 feet east.

The local variations in permeability are evident from this figure. The water level in I-5, I-7, and the HE well dropped to within a few feet of the bottom within one hour while the level in 8-OW, which is only a few feet away from P-1, remained well above the top of the coal.

## Air Flow Tests

Air flow tests were begun by injecting air into well I-0 at about 15 psig. The pressure was gradually raised to 60 psig and the flow allowed to stabilize. No leakage to the surface was observed but pressures of up to 40 psig were observed in wells 100 feet away. Air losses to the underground system were approximately 40% for this mode of operation.

The I-0 well was drilled and cased to the top of the coal seam. The rubble filled explosion cavity extends completely through the coal. Thus, with the cavity dewatered, injecting air into I-0 puts high pressure on the entire cavity leading to many possible paths for leakage to the surroundings. The hydrology data suggests that good communication paths exist from the I-0 well to DW-6, DW-1 and presumably to the environmental wells EM-1 through 6.

Reversing the air flow and injecting in well P-1 put high pressure at the bottom of the seam. This reduced the pressure in the I-0 well and also reduced the air losses. About 95% of the injected air was recovered in this mode of operation.

Because of the large air loss found when injecting in I-0 we decided to reverse our original intention and gasify from well P-1 to well I-0.

Two SF<sub>6</sub> tracer runs were made, one for each flow direction. These tests were quite successful and implied an accessible void volume of about 600 ft<sup>3</sup>.

## GASIFICATION

### Ignition

Electrical resistance heating (1 Kw) was used to ignite the coal. Two electric barbecue charcoal lighters were strapped together and lowered down the P-1 well along with a thermocouple. Several bags of charcoal briquets were dumped down the well until the lighters were covered. Once all valves were properly set and the air flow turned on, the charcoal ignited in a few minutes, as indicated by the thermocouple. Ignition took place at 16:30 on Oct. 15, 1976 (Julian day 289.7). The injection and production flow rates are shown in Fig. 5 for the entire experiment.

### Gasification History

As mentioned previously a good communication path was established through the bottom part of the coal seam between well P-1 and well I-5, in the center of the zone as shown in Fig. 2. We expected that the burn would progress along this path and then travel upward and go along the top of the seam to well I-0. At first this seemed to be the case. Operating with an input pressure of about 60 psig, the flow dropped from 130 scfm to 100 scfm during the first two hours after ignition, and then the flow rose steadily for the rest of the day. Thermocouples in two of the wells, I-7 and I-5 responded within a hour of ignition. Temperature of about 100°C were recorded at the 142 foot level, two-thirds of the way into the coal seam at both wells. This situation is illustrated in Fig. 6. Here, the thermocouple wells and injection and production wells are shown in their relative positions with the top of the coal seam indicated by a tic mark to the left of the vertical scale. (The vertical distance scale factor is twice the horizontal scale factor.) Injection and production flows are indicated by arrows where the length of the arrow is proportional to the flow rate.

On the second day of gasification (day 290) temperatures began to rise in wells I-1, I-6, I-8, and DW-4 as shown in Fig. 7. At about 290.6 the output flow increased sharply to 1300 scfm and a large quantity of water was produced. The injection pressure was lowered several times to control the flow. After a few hours of controlled production the flow increased suddenly to over 2400 scfm accompanied by the emission of coal fines mixed with tar. All of the pressure and gas sampling lines were quickly plugged as well as the production flow meter orifice plate. The bypass line around the flow meter section was opened to shunt the gas flow while repairs were being made. The temperature distribution given in Fig. 8 clearly shows the override at this time.

The heating value of the produced gas is shown in Fig. 9. The steady decline in the days following the breakthrough is evident. The temperature distribution on day 291.7 and 292.9 are shown in Figs. 10 and 11. The increase in temperature near the top of the seam in wells I-4, I-6, and I-7 is indicative of the creation of an override path along the top of the coal seam. The distribution on day 294.9, Fig. 12 shows that although the burn is predominantly near the top of the coal, there is some indication of burning in the bottom half of the seam especially at I-1.

A high flow test was run on day 295.5 - see Fig. 5. However, as can be seen in Fig. 9 the heating value did not change appreciably except for a temporary dip at the end of the test. No major changes in temperature were noted during this test.

During the high flow test we tried a period of water injection into the input well, P-1. From 1 to 2 gpm of water was injected which is almost equal to the natural influx. No measurable effect on any parameter was found. This is further evidence that the burn was near the top of the coal at this time.

By day 297, the burn front was close enough to the production well, I-0 so that the output gas temperature had reached 400°C and was still climbing. A small leak had developed in the grout seal around the well casing and the valve gaskets were being seriously overheated. An attempt was made to cool the gas by flooding wells DW-1 and DW-6. Although a slight decrease in well head temperature was noted, the main effect was to increase the production flow rate and to increase the heating

value of the gas to 150 Btu/cuft. This caused the flare stack temperature to climb so the attempt was stopped and the pumps turned back on.

Reducing the flow rate by cutting the input pressure helped to reduce the output temperature but it also caused a serious deterioration in the heating value of the gas. Raising the pressure did not restore the heating value to its original point and the deterioration continued. The compressor was shut down and the gasification experiment terminated on day 300. Figure 13 shows the temperature distributions at this time.

#### Gasification Results

Gasification proceeded for 11 days. During this time approximately 10 MMSCF of air were injected and 19 MMSCF (13.2 MMSCF dry) of gas were produced. Initial air injection pressure was approximately 70 psia which fell rapidly on the second day of operation to a value of 25-30 psia. Production pressures were generally about 5 psi lower. The rapid decrease in injection pressure was a result of the rapid increase in flow conductance of the formation.

The rapid change in conductance during the initial portion of the gasification is shown in Fig. 14. Just after ignition the relative conductance fell rapidly and then recovered to approximately 70% of its pregasification level and maintained this level for approximately 1/2 a day. At this point the rapid rise occurred and during the course of most of the gasification the conductance was 50 to 100 times its pregasification value.

Gas losses during the gasification were only significant during the early high pressure operations. Figure 15 shows the integrated gas recovery (based on a nitrogen balance) as a function of time. It shows an ultimate recovery of 93% of the injected nitrogen.

The dry gas composition, as measured by gas chromatograph, for the primary gas components are shown as a function of time in Figs. 16 and 17. A higher percentage of pyrolysis gases were apparently present during the first two days of the test resulting in a higher methane concentration. During the central portion of the tests gas composition was relatively stable. This was followed by a marked decline in CO, H<sub>2</sub>, and CH<sub>4</sub> levels occurring near the end of the test as the oxidation zone approached the exhaust well. No influence on composition can be seen as a result of the high flow test. However, a definite change in the composition is indicated during and after the injection of the water slug. This consists of a rapid rise in hydrogen concentration followed by a rapid decline in H<sub>2</sub>, CO, and CH<sub>4</sub>.

Considerable quantities of water were produced from the area in the form and liquid and gas during the gasification test. Liquid water was produced by pumps located in the DW wells. Steam was produced from the gasification production well. The steam accounted for 30% of the total produced gas volume (see Fig. 18).

The burn geometry as deduced from the thermocouple data and coal consumption estimates is shown in Fig. 19a (plan view) and Fig. 19b (elevation view). The burn started at the bottom of well P-1 and was progressing horizontally towards well I-5 and also vertically toward the top of the seam. After the blow-out the burn went mostly along the top of the seam but also continued along the central line at lower elevation in the coal.

The total energy recovery in the form of combustible gas was 65% of that available from the estimated 128 tons of consumed coal. The total energy balance is shown in Fig. 20. Note that if the combustion energy estimated to be present in the produced tars is included as useable energy the total useful energy recovery becomes approximately 73%. The underground losses of heat energy were quite small. The largest energy loss from the system was due to the production of a considerable amount of steam.

#### Conclusions - A. Explosive Fracturing

Hoe Creek experiment No. 1 is probably one of the most thoroughly diagnosed fracture experiments ever performed by our laboratory. We feel that the general agreement between experiment and our one and two dimensional codes SOC and TENSOR is quite good in predicting the degree of fracture. There are still some details that are not clear. The layered appearance of the fracturing and the rather large scale asymmetries as a function of azimuth from the shot points are hard to understand in what appears to be a very homogeneous coal seam.

Our knowledge of the relationship of degree of fracture to permeability is much less satisfactory. In fact, comparing the results from the Kemmerer and Hoe Creek experiments, it is obvious that total failure strain, (shear plus tensile), is not a reliable predictor of permeability. We are looking into the possibility that tensile failure (11) may be more directly related to permeability.

The results from the Hoe Creek experiment indicate that spherical HE shots placed at the bottom of the coal seam will not produce a permeability distribution that is suitable for gasification. Other geometries and types of explosive fracture are under consideration for future experiments. (12)

#### Conclusions - B. Gasification

Forward combustion gasification was achieved without any problem of plugging of the formation. After two days of operation, flow conductivity was an order of magnitude above pre-gasification levels. However, even before this short circuit condition was reached, plugging did not seem to be serious.

Injecting air at well I-0 resulted in unacceptably high losses. Reversing the flow direction for gasification so that well I-0 was kept as close to atmospheric pressure as possible reduced the overall loss rate to 7%.

The short circuiting of the flow which occurred after 28 hours of gasification, limited the total volume of coal gasified.

The gas composition, gas heating value and oxygen utilization were all fairly constant during the course of the burn. Marked change occurred only at the end of the experiment. Gas composition was not influenced by doubling the air injection rate.

The total water influx into the gasification region was about 65% of the pre-gasification level. About 30% of this amount entered the hot zone. However, this water influx did not appear to influence the product gas composition, indicating that it mixed with the hot gas after the reactions were completed. However, the influx of water into the system may have limited the amount of coal recovered by limiting the lateral spreading of the burn zone.

Energy recovery in the form of produced products amounted to 75% of the energy in the consumed coal. There were essentially no losses to the subsurface formation. The greatest energy loss took the form of the production of steam.

"Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Energy Research & Development Administration to the exclusion of others that may be suitable."

#### NOTICE

"This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research & Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately-owned rights."

# REFERENCES

- (1) G. H. Higgins, "A New Concept for In Situ Coal Gasification," Lawrence Livermore Laboratory, Rept. UCRL-51217 (1972).
- (1a) D. R. Stephens, F. O. Beave and R. W. Hill, LLL In Situ Coal Gasification Program, Lawrence Livermore Laboratory, Rept. UCRL-78308 (1976); also in Proceedings 2nd Underground Coal Gasification Symposium, Morgantown, W. Va., August, 1976.
- (2a) J. R. Hearst, T. Butkovich, E. Laine, R. Lake, D. Leach, J. Lytle, J. Sherman, D. Snoeberger, R. Quong, "Fractures Induced by a Contained Explosion in Kemmerer Coal," Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. Vol. 13, pp. 37-44, Pergamon Press 1976. Printed in Great Britain.
- (2b) T. Butkovich, "Correlation Between Measurement and Calculations of High Explosive Induced Fracture in a Coal Outcrop," Lawrence Livermore Laboratory, Rept. UCRL-76984 (1975).
- (3) LLL In Situ Coal Gasification Program, Quarterly Progress Report, July through September 1975, Lawrence Livermore Laboratory, Rept. UCRL-50026-75-3 (1975).
- (4) Randolph Stone, David F. Snoeberger, "Evaluation of the Native Hydraulic Characteristics of the Felix Coal (Eocene, Wasatch Formation) and Associated Strata, Hoe Creek Site, Cambell County, Wyoming, Lawrence Livermore Laboratory, Rept. UCRL-51992.
- (5) LLL In Situ Coal Gasification Program, Quarterly Progress Report, October through December 1975, Lawrence Livermore Laboratory, Rept. UCRL-50026-75-4 (1976).
- (6) R. W. Hill and C. B. Thorsness, UCRL (in preparation).
- (7) LLL In Situ Coal Gasification Program, Quarterly Progress Report, January through March 1976, Lawrence Livermore Laboratory, Rept. UCRL-50026-75-4 (1976).
- (8) LLL In Situ Coal Gasification Program, Quarterly Progress Report, July through September 1976, Lawrence Livermore Laboratory, Rept. UCRL-50026-76-3 (1976).
- (9) D. F. Snoeberger, Field Hydroles, Test of Explosively Fractured Coal, Lawrence Livermore Laboratory, Rept. UCRL-78957 (1977).
- (10) LLL In Situ Gasification Program, Quarterly Report, April through June, 1976, Lawrence Livermore Laboratory, Rept. UCRL-50026-76 (1976).
- (11) T. R. Butkovich, Calculation of Fracture and Permeability Enhancement from Underground Explosions in Coal, Lawrence Livermore Laboratory, Rept. UCRL-77945.
- (12) T. R. Butkovich (in preparation).

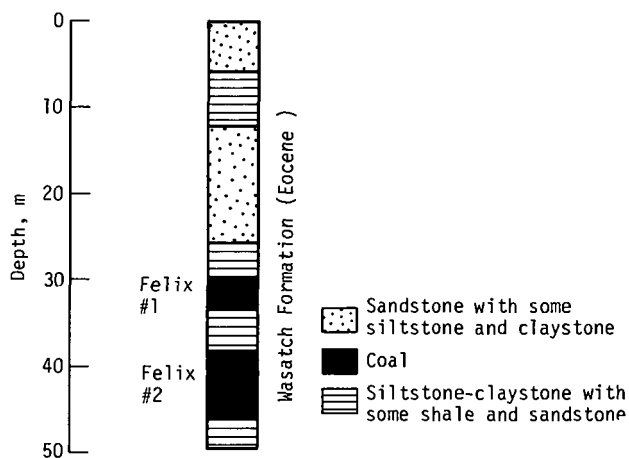


Fig. 1 Site stratigraphy obtained from cored wells.

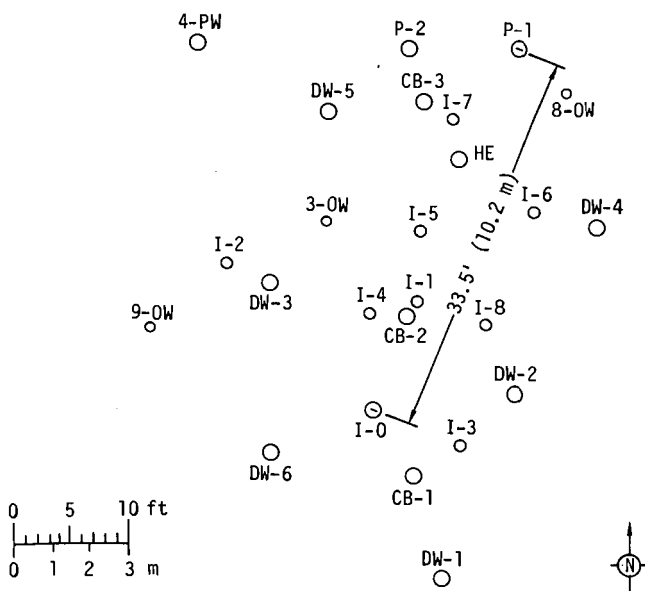


Fig. 2 Hoe Creek Experiment I plan view showing bottom hole locations. Well 3-OW was sealed off before gasification.

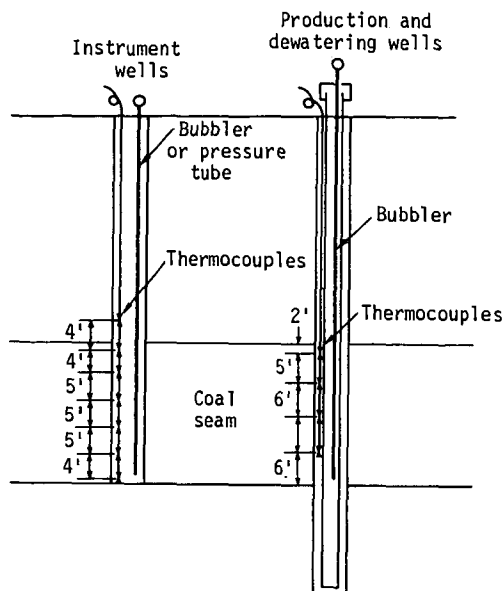


Fig. 3 Typical subsurface instrument placement.

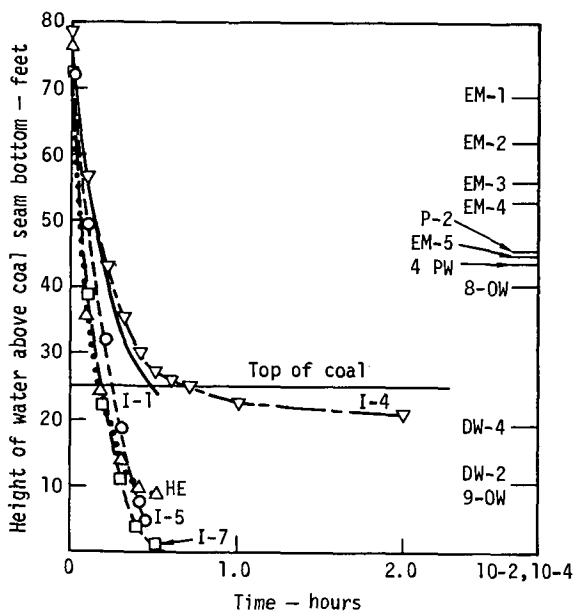


Fig. 4 Water levels at several locations within the fracture zone as a function of time after the start of dewatering. The levels indicated on the right are those reached after three to five days of pumping.

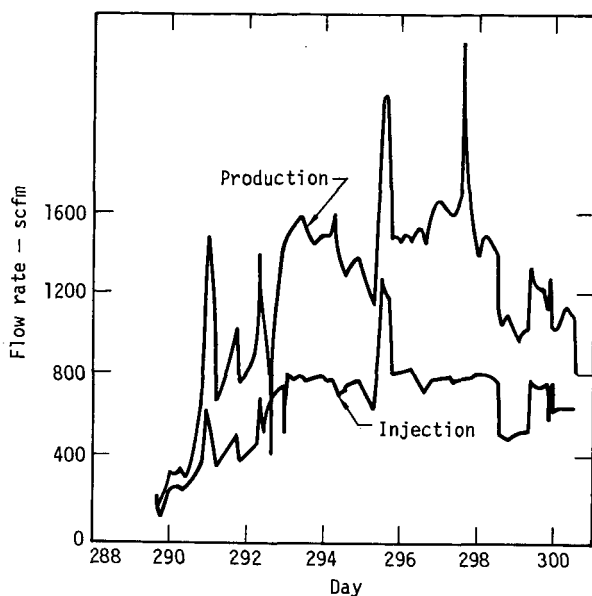


Fig. 5 Injection and production flow rates for the entire gasification experiment. The production flow was calculated from a nitrogen balance for the period 291.4-292.2 when the production flow meter was bypassed.

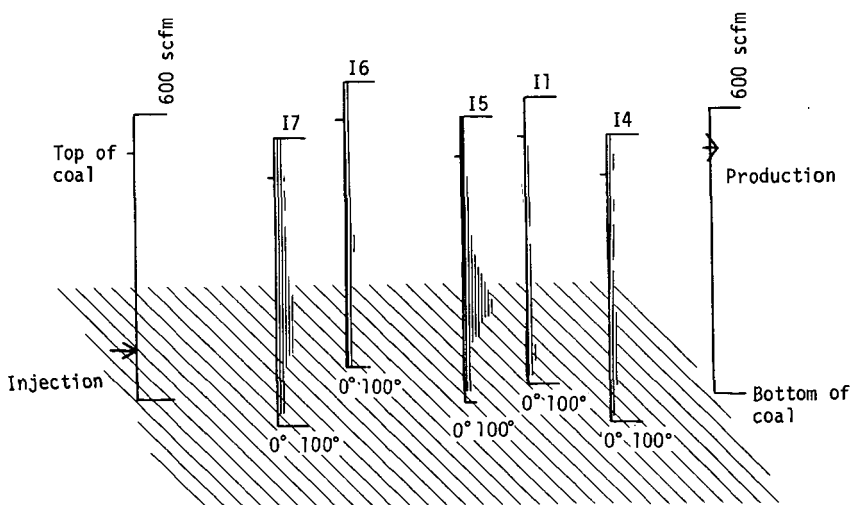


Fig. 6 Temperature profiles in the instrument wells on day 289.74. The wells are shown in relative positions in the coal seam. The vertical distance scale factor is twice the horizontal scale factor. The length of the arrows marking injection and production points are proportional to the flow rates.

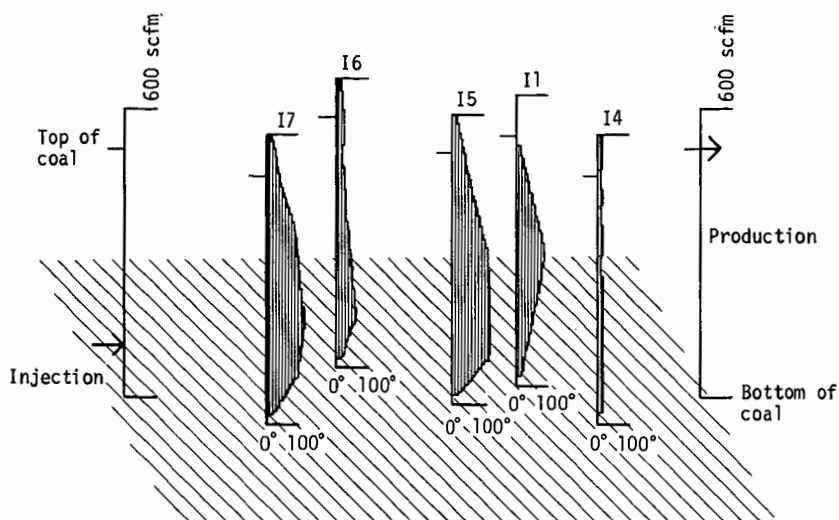


Fig. 7 Temperature profiles in the instrument wells on day 290.60. The wells are shown in relative positions in the coal seam. The vertical distance scale factor is twice the horizontal scale factor. The length of the arrows marking injection and production points are proportional to the flow rates.

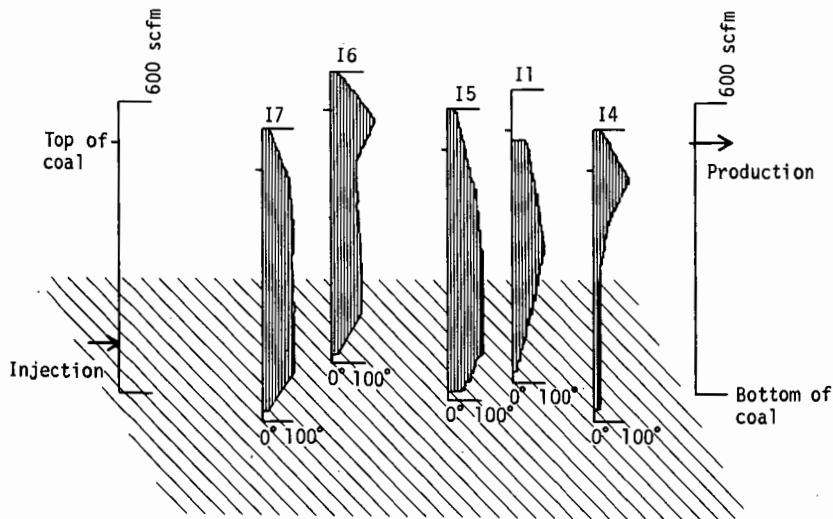


Fig. 8 Temperature profiles in the instrument wells on day 291.2. The wells are shown in relative positions in the coal seam. The vertical distance scale factor is twice the horizontal scale factor. The length of the arrows marking injection and production points are proportional to the flow rates.

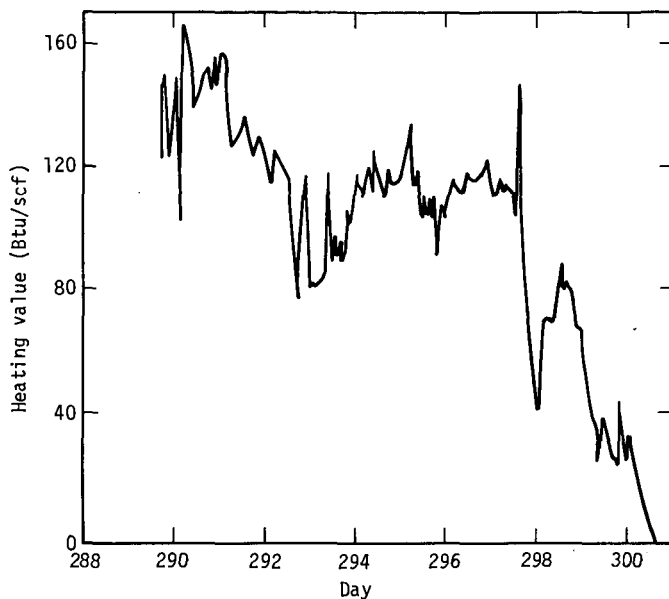


Fig. 9 Dry gas heating value during gasification.

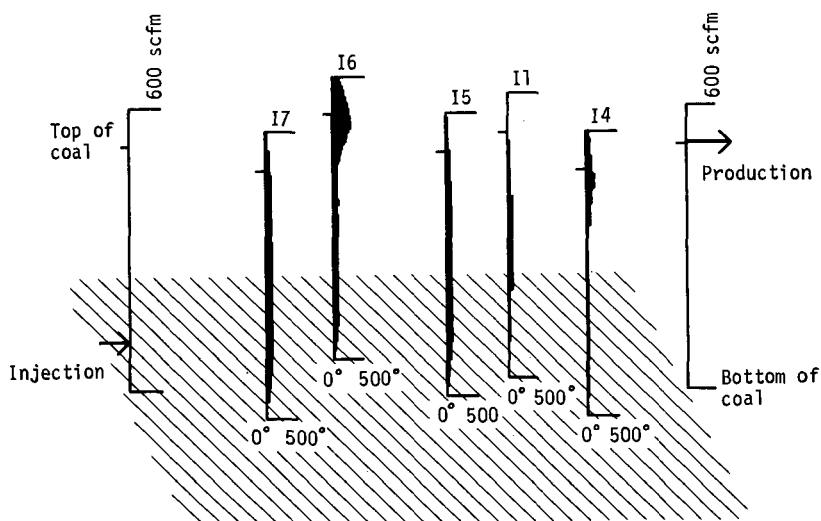


Fig. 10 Temperature profiles in the instrument wells on day 291.70. The wells are shown in relative positions in the coal seam. The vertical distance scale factor is twice the horizontal scale factor. The length of the arrows marking injection and production points are proportional to the flow rates.

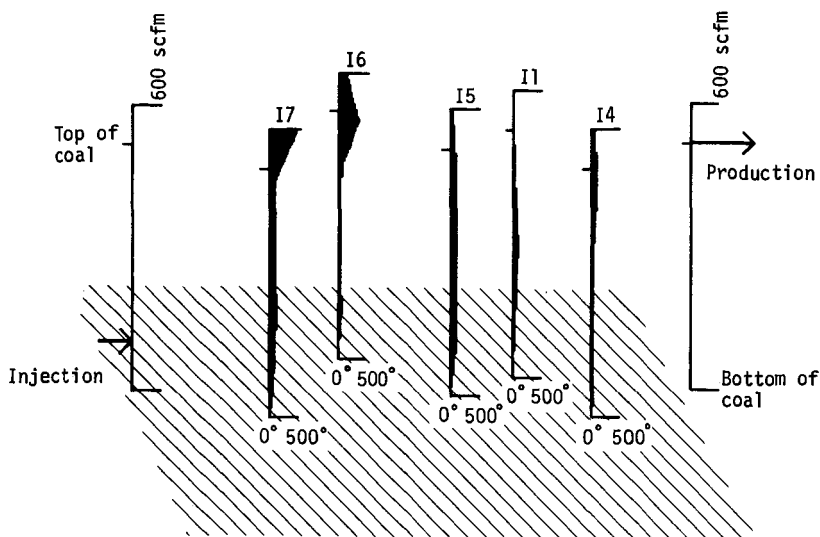


Fig. 11 Temperature profiles in the instrument wells on day 292.94. The wells are shown in relative positions in the coal seam. The vertical distance scale factor is twice the horizontal scale factor. The length of the arrows marking injection and production points are proportional to the flow rates.

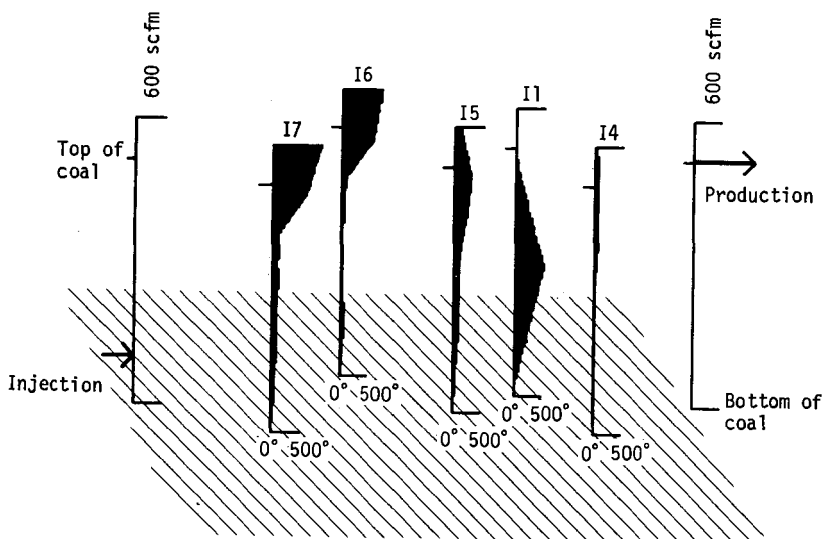


Fig. 12 Temperature profiles in the instrument wells on day 294.94. The wells are shown in relative positions in the coal seam. The vertical distance scale factor is twice the horizontal scale factor. The length of the arrows marking injection and production points are proportional to the flow rates.

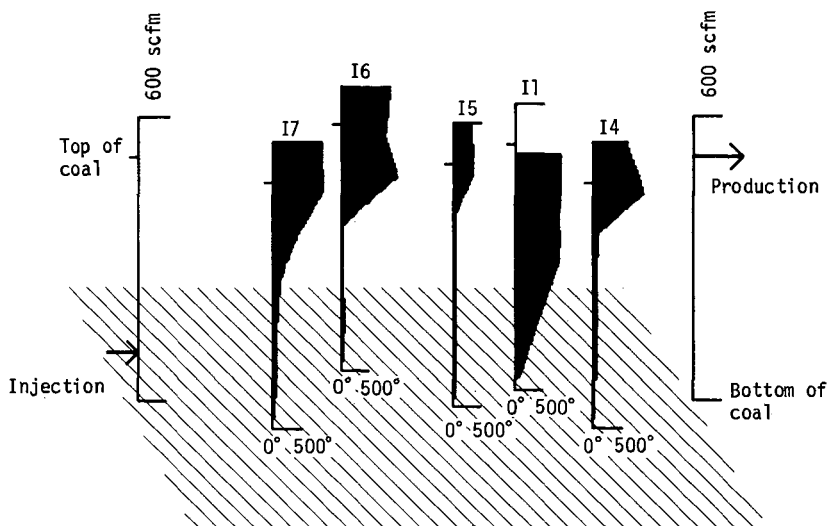


Fig. 13 Temperature profiles in the instrument wells on day 300.26. The wells are shown in relative positions in the coal seam. The vertical distance scale factor is twice the horizontal scale factor. The length of the arrows marking injection and production points are proportional to the flow rates.

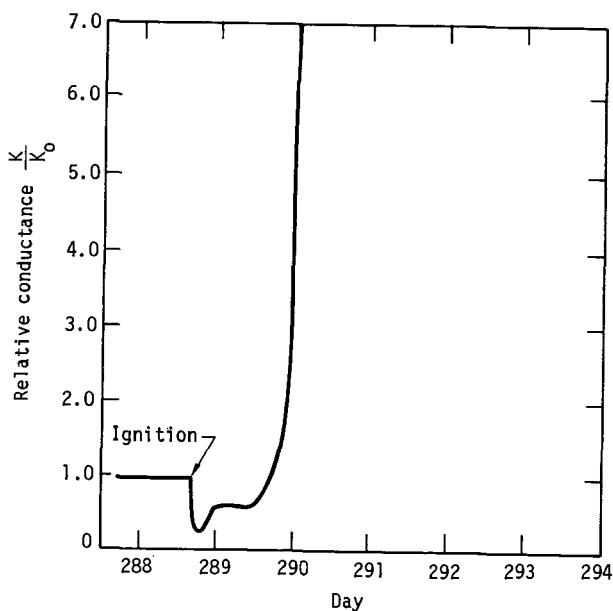


Fig. 14 Relative formation conductance between injection and production well.

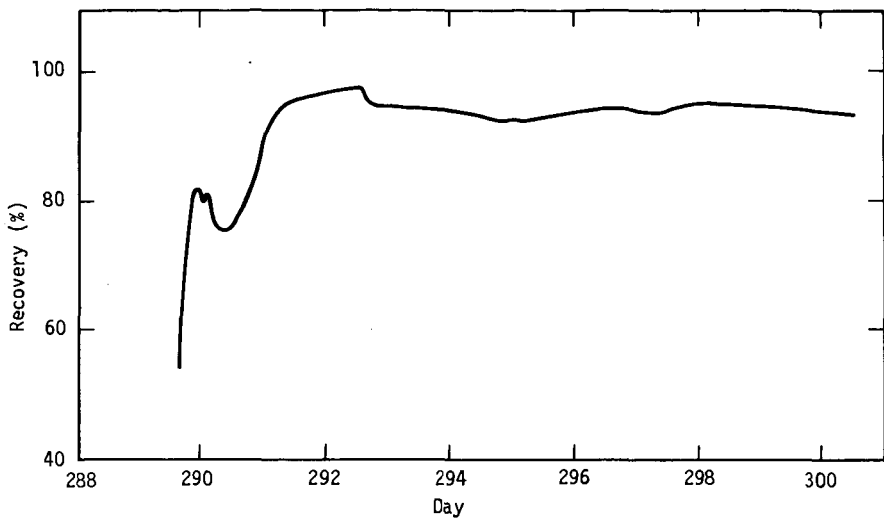


Fig. 15 Integral percent gas recovery during gasification.

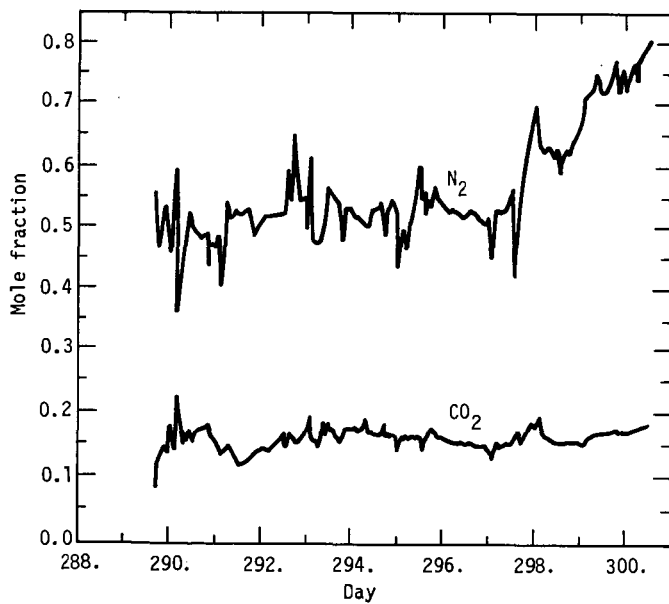


Fig. 16 Dry gas mole fractions of N<sub>2</sub> and CO<sub>2</sub> in product gas.

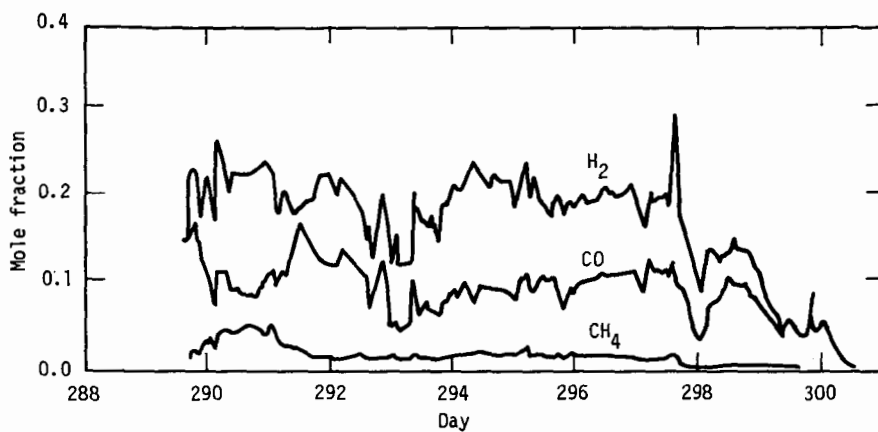


Fig. 17 Dry gas mole fractions of H<sub>2</sub>, CO, and CH<sub>4</sub> in product gas.

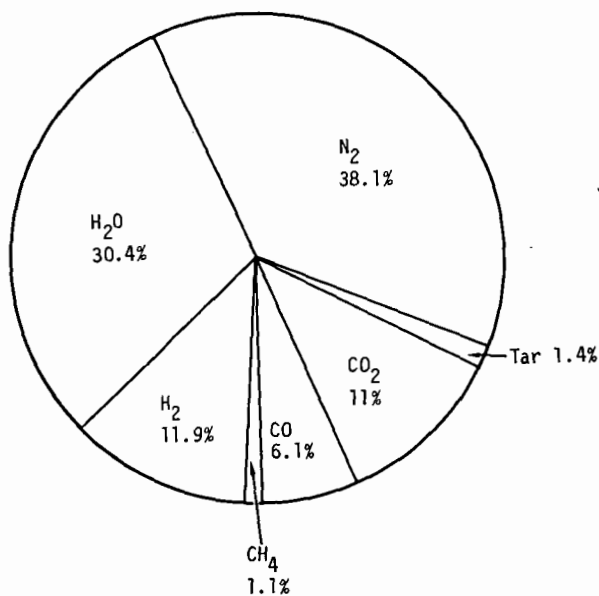


Fig. 18 Major gas product distribution on a mole basis.

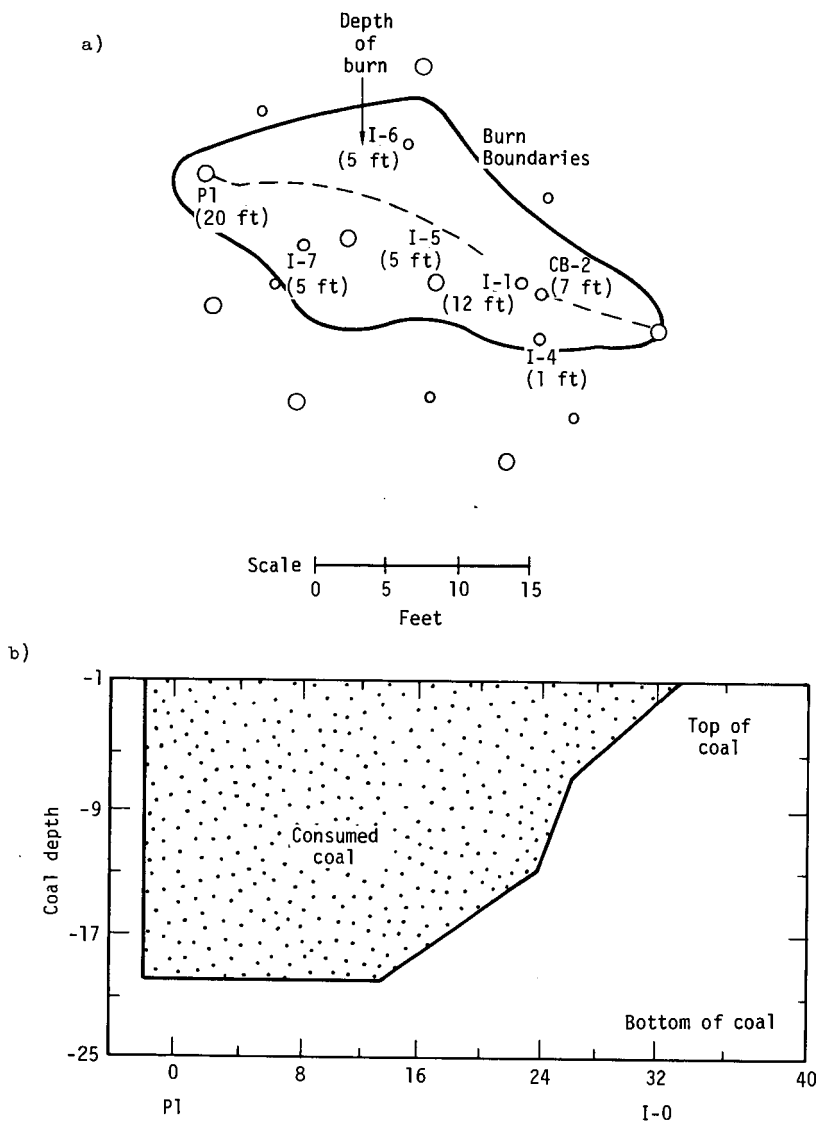


Fig. 19 a) Plan view, and b) centerline elevation view of gasified volume as estimated from temperature measurements. The depths given in parentheses indicate burn depth at that point.

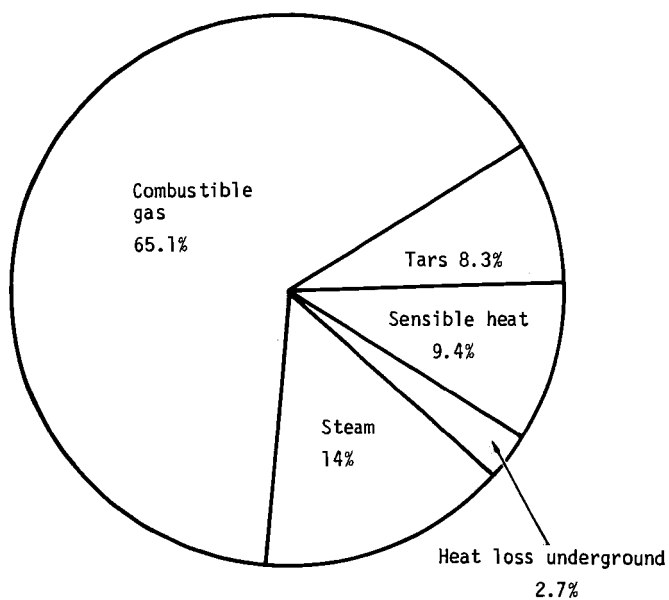


Fig. 20 Energy distribution in the gasification as a percent of consumed coal energy.